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The Guided Parafoil Airborne Delivery System Program[1]

by

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Abstract

The U.S. Army Natick RD&E Center has expressed a need for advanced technology related to cargo airdrop systems in general as well as several specific areas of interest. A scenario of particular interest is the high altitude offset delivery of heavy payloads utilizing autonomous guidance, navigation and control, and a soft landing. The basis of the technical approach to this requirement is the mating of two existing technologies: a large scale parafoil developed by Pioneer Aerospace during the NASA Advanced Recovery Systems (ARS) program and the ORION™ GPS based navigation, guidance and control system developed by SSE, Inc. for smaller parafoils. The combination of these two technologies is the centerpiece of the Guided Parafoil Airborne Delivery System (GPADS) test program. The primary objective of the program is to demonstrate the applicability of a high glide recovery system to the stabilization, deceleration and precision touchdown of a wide variety of military payloads at preselected sites. The basic drop test sequence of events for the GPADS program is described. Modifications were made to the ARS configuration and operations sequence to adapt the existing hardware to the Military Airdrop Mission envisioned by Natick. Modifications include direct deployment of the parafoil by the extraction parachute, incorporation of a versatile separable confluence fitting, integration of autonomous GPS based guidance and control and incorporation of a larger parafoil canopy to increase payload capacity. The new large scale (7,350 ft^2) GPADS parafoil is described in detail.

INTRODUCTION

Development of the Guided Parafoil Airborne Delivery System (GPADS) is a U.S. Army Soldier System Command, Natick Research, Development and Engineering Center Advanced Technology Demonstration (ATD) program entitled Advanced Airdrop for Land Combat. GPADS is a member of the Advanced Precision Airborne Delivery System (APADS) family, a family of autonomously guided, high altitude, offset delivery airdrop systems for precision delivery of military equipment, vehicles, and supplies. Each system is comprised of a gliding, non-powered, delivery platform integrated with an autonomous Global Positioning System (GPS) based navigation, guidance and control system (NGCS). The objective of the ATD is to demonstrate the GPADS with the capabilities in Table 1.

Table 1, GPADS OBJECTIVES	ATD Threshold	ATD Goal
Altitude (ft MSL)	20,000	25,000
Payload Wt (lb)[2]	22,000	36,000
Gross Weight	28,000	42,000
Impact Velocity (feet/second)	30	8
Guidance	autonomous	autonomous
Precision (Meters CEP)[3]	100	100
Offset Distance (feet)[4]	54,000	67,500

1. The ATD thresholds are the minimum required performance criteria.
2. The difference between the estimated payload weight and the gross (rigged) weight is the additional weight of the airdrop system components (parachutes, platforms, etc.).
3. Delivery precision is indicated in meters circular error probability. This means that the payload will land within

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the indicated distance from the target at least 50% of the time.

4. The offset distance when deployed from 25,000 feet Above Ground Level (AGL).

Natick has teamed with the Early Entry Lethality and Survivability Battle Lab, Pioneer Aerospace Corporation and SSE Incorporated for the development of GPADS.

BACKGROUND

In both the rapid worldwide insertion of CONUS-based initial forces and the resupply of rapidly moving forces, airdrop operations and capabilities are more important than ever before. Changing world environment coupled with a smaller, multi-roled, contingency-based military force necessitates the development of a flexible, high-altitude offset airdrop capability. GPADS will provide the warfighter with a new capability, the ability to autonomously deliver combat essential payloads accurately from high altitudes and offset distances. Current airdrop operations require delivery aircraft to fly directly over the designated drop zone (DZ) at relatively low altitudes (1,300 feet Above Ground Level (AGL)) in order to accurately deliver payloads using the conventional Low Velocity Airdrop System (LVADS). LVAD operations greatly increase the vulnerability of the delivery aircraft to opposing air defense weapons and small arms fire and compromises the location of friendly ground forces. The high altitude, standoff delivery capability provided by GPADS will significantly reduce aircraft vulnerability in non-permissive airdrop environments where small arms, light AAA and man-portable missiles are prevalent threats. GPADS offers other tactical advantages to theater forces through the GPS-based guidance technology. Current air delivery systems are inaccurate at higher altitudes and cannot be employed during adverse weather conditions, which affect visibility and the ability to locate a designated drop zone. Effective employment of these systems often requires a man on the ground to ensure accurate delivery. A comparable "smart bomb" effect in terms of precision "drop and forget" capability does not currently exist, but would enhance the capability of the military to respond to a broader spectrum of air delivery missions at night and in poor visibility conditions. Precision offset/high altitude air deliveries will still be susceptible, to a lesser extent than current unguided air delivery systems, to meteorological effects, such as very high winds or icing conditions. The delivery accuracy and precision that results from the GPS guidance allow for smaller drop zones and reduced load dispersion on the DZ, resulting in faster force consolidation. GPADS provides a "Just In Time" resupply capability which will allow for pre-positioning of supplies ahead of rapidly moving combat forces and covert delivery of supplies to isolated units and special operations forces.

DEVELOPMENT APPROACH

The heavy payload, precision, and impact velocity required for GPADS result in technical barriers in the areas of very large parafoil deployment, automated guidance and control of non-powered gliding decelerators, and automated soft landing. Parafoils large enough to recover 42,000-pounds had previously never been successfully deployed. Although GPS guidance of missiles and small fixed wing vehicles has been successfully demonstrated, this technology had not been demonstrated on large non-powered gliding decelerators. The technical challenge is in the characterization of the decelerator. The ability to predict the decelerator's response to control inputs is critical to achieving the required precision. Execution of the parafoil flare maneuver essential for soft landing is an additional technical barrier. This maneuver has never been accomplished using automated methods with a large parafoil canopy. A microprocessor based system to assess position, wind speed, altitude, and horizontal and vertical velocity data must be developed to precisely trigger the parafoil flare sequence.

These risks are minimized with the integration of two existing technologies: the large scale parafoil developed by Pioneer for the NASA-MSFC Advanced Recovery System (ARS) and the ORION™ GPS-based NGCS developed by SSE, Incorporated. Pioneer had previously successfully demonstrated the deployment and recovery of 15,000-pounds with a 3,600 ft^2 parafoil utilizing mid-span reefing. The parafoil, the extensive wind tunnel test data and data from live airdrop testing gathered during the ARS program has been leveraged for GPADS minimizing the risk associated with development of a 42,000-pound capacity parafoil. The 3,600 ft^2 parafoil integrated with the ORION™ NGCS was chosen as the baseline GPADS configuration. SSE, Incorporated, the guidance system subcontractor for GPADS, has demonstrated automated guidance and control of a 1,000-pound capacity parafoil with their ORION™ system. Application of the characterization data for the 3,600 ft^2 parafoil and use of the ORION™ system significantly minimizes the technical risk associated with meeting the GPADS accuracy and impact velocity requirements.

The ARS configuration was used as the baseline GPADS configuration. Upgrading the baseline system to meet Army performance requirements is being accomplished in five phases:

Phase 1 - Integration of the NGCS into the existing 15,000-pound capacity parafoil.

Phase 2 - Design, fabrication and testing of the 42,000-pound capacity parafoil.

Phase 3 - Integration of the NGCS with the large parafoil.

Phase 4 - Development of a soft landing capability.

Phase 5 - Advanced Technology Demonstration.

Phase 2 of the program has recently been successfully concluded and Phase 3 is under way. Phase 2 had several test objectives. Perhaps the most important of these was to design, manufacture and test a new 42 Klb capacity parafoil. This canopy is based on the successful 3,600 ft^2 design and incorporates lessons learned during ARS and Phase 1 of GPADS testing. Goals for this canopy include demonstrating proper deployment and control and obtaining a full set of performance data. Control of the parafoil is through the existing NGCS. Both guided and unguided drops are planned. Parafoil performance data acquired during Phases 2 & 3 will enable modification of NGCS algorithms to match the performance of the 42 Klb wing. The balance of this paper describes the 7,350 ft^2 parafoil.

DROP TEST ITEM

The test item for GPADS Phases 2 & 3 is a 39 cell parafoil (Pioneer P/N 15330). Each inlet constitutes a cell (there are no unloaded ribs). The structural design requirements were based on the direct deployment of a 36,000 lb payload from an aircraft flying at 150 knots CAS (q≅76 psf). It is designed to function with a total descent weight not to exceed 42,000 lb. Inflation is managed by means of Pioneer's patented span-wise reefing system in three stages. The first stage of the parafoil has a canopy area of 1,700 ft^2 constructed of 4.0 oz/yd^2 nylon fabric. The first stage suspension lines are fabricated from 4,000 lb tensile strength Kevlar braided cord. The canopy area with second stage deployed is 4,344 ft^2. The second stage itself (approximately 2,644 ft^2) is constructed of 3.0 oz/yd^2 nylon fabric, with suspension lines fabricated of 4,000 lb Kevlar cord. The full open canopy area is 7,365 ft^2. The 3,021 ft^2 third stage is constructed of 2.0 oz/yd^2 fabric and suspension lines are fabricated from 1,500 lb Kevlar cord. The suspension lines are of equal length to facilitate manufacturing. Rigging angle is set via differential riser length (shorter in front). The trailing edge lines are retracted ~8.5 feet during inflation, followed by a pyrotechnically initiated brake release. The parafoil assembly is illustrated in Figure 1. The canopy materials are summarized in Table 2.

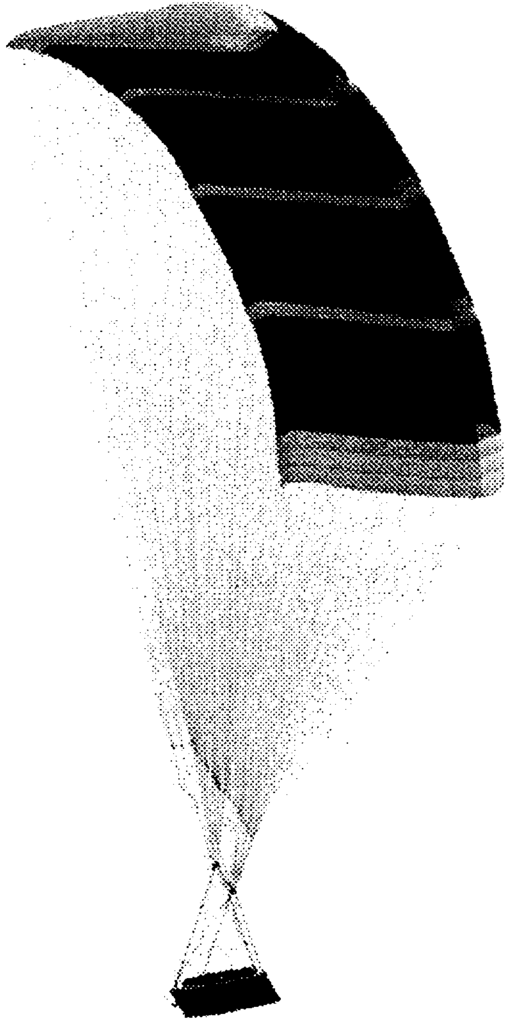
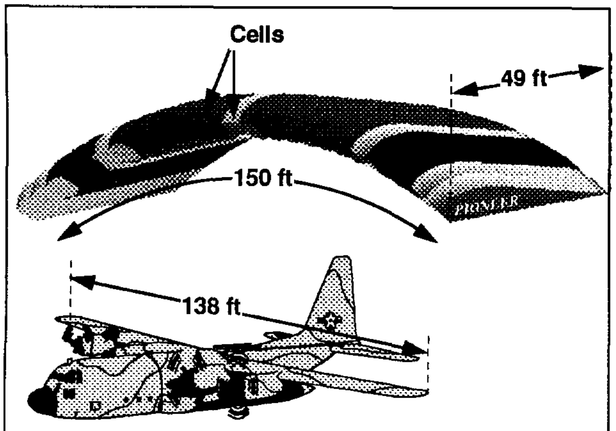


Figure 1: 7,350 ft^2 PARAFOIL

Materials	1st Stage	2nd Stage	3rd Stage
Canopy Fabric	4 oz/yd^2 Nylon	3 oz/yd^2 Nylon	2 oz/yd^2 Nylon
Suspension Lines	4000 lb Kevlar	4000 lb Kevlar	1500 lb Kevlar

Table 2, MATERIALS SUMMARY



C-130 Cargo Plane
Drop Aircraft for GPADS

Figure 2, PARAFOIL SIZE COMPARISON

To put the size and scale of the parafoil canopy in perspective, some reference points may be useful:

- Wing Area: 7,350 ft^2.
    - Bigger than a 747 or C-5
    - More wing area than any modern day aircraft
    - The C-130 from which it is dropped has a wing area of 1,745 sq. ft.
- Dimensions:
    - Chord: 49 ft.
    - Span: 150 ft. (C-130 span is 138 ft.)
    - suspension system: 175 ft
    - Packed volume: 63.4 ft^3 (3.2' x 4' x 5')
- Number of Cells/Ribs: 39/40
- Weight:
    - Wing cloth: 700 lb.
    - Complete Pack: 1600 lb.
- Suspension Lines:
    - Number: 559
    - Total length: ~18 miles Total material strength: 1,780,000 lb.

DROP TEST CONFIGURATION/SEQUENCE

The GPADS drop test configuration consists of a programmer parachute(s), parafoil assembly, separable

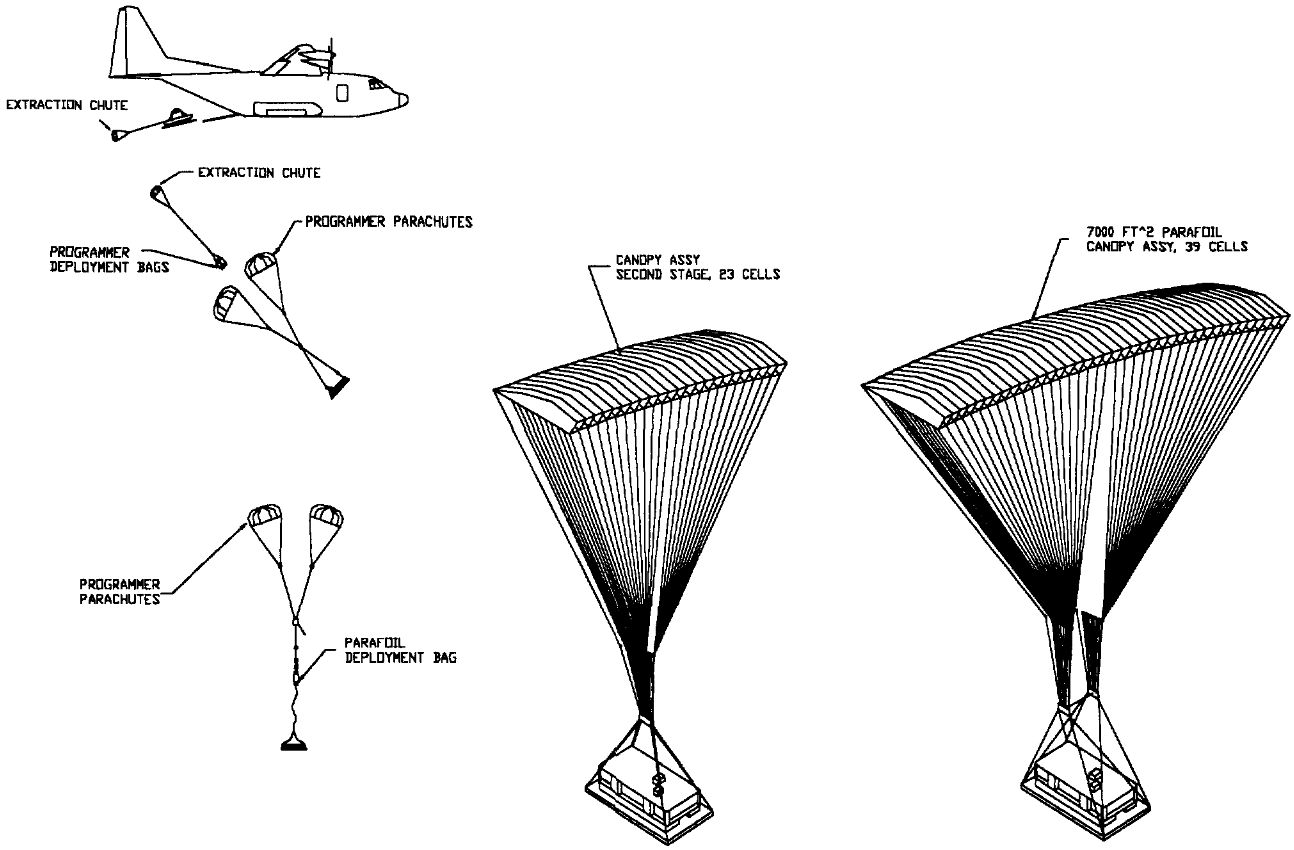


Figure 3; DROP TEST DEPLOYMENT SEQUENCE

confluence fitting and drop test vehicle (DTV). The test configuration and sequence of operations is depicted in Figure 3.

The drop tests are conducted at the U.S. Army's Yuma Proving Ground, Arizona using standard cargo airdrop techniques and equipment. A C-130 aircraft is used to drop a standard airdrop platform containing the requisite weight, control devices, instrumentation, telemetry equipment and test items.

The nominal test operations sequence begins with extraction of the drop test assembly from the aircraft by a government furnished extraction parachute sized for the payload weight. As the platform separates from the aircraft, load transfer occurs and a cluster of 60 ft D_o programmer parachutes (1-3; depending on weight) is deployed in a reefed condition. Four seconds later, programmer disreef is initiated by pyrotechnic reefing line cutters. After 10 seconds, the programmer parachute cluster is released from the DTV by four electronically activated pyrotechnic cutters and deploys the reefed 39 cell parafoil. The parafoil remains in its first stage reefed condition (9 cells) for approximately 12 seconds followed by a disreef to second stage, expanding the canopy to 23 inflated cells. The parafoil remains in the second stage reefed condition for approximately 8 seconds followed by a two step disreef of the third stage. The third stage disreefs in two equal segments, one half at 20 seconds and the second half at 27 seconds. The reconfiguration of the confluence fitting (from single point to two point) also takes place at 27 seconds into the deployment sequence. The trailing edge of the parafoil remains fully retracted for approximately 13 seconds after the confluence fitting separates. At this time, a pyrotechnically initiated brake release event occurs. The control lines are installed with a 3 ft trailing edge retraction differential (6 ft left, 3 ft right) which results in the automatic initiation of a slow left hand turn which remains until the NGCS takes command.

TEST DATA

At this writing the 7,350 ft^2 GPADS canopy had been flown three times; with total descent weights of 12,500 lb, 22,000 lb and 28,500 lb respectively. While the latter represents the heaviest weight ever recovered by a parafoil, is still significantly less than the canopy's design payload. The first two tests were unguided deployment verification flights. The third flight was conducted with an operational Nav, Guidance and Control System (NGCS). Table 3 summarizes the test conditions to date. Subsequent drop tests will incorporate increasing weight and altitude and will all be guided. While it is too early to characterize the glide performance and control response of the canopy, the initial data gathered during Phase 2 appear consistent with the glide ratios measured for the smaller 3,600 ft^2 canopy; i.e. glide ratios in the 2.8 - 3.0 range.

Test	Date	W_d (lb)	Altitude (ft AGL)	Guided
DT 2-3	10/19/94	12,000	6,000	no
DT 2-5	1/10/95	22,000	6,000	no
DT 3-1	3/15/95	28,500	15,000	yes

Table 3, TEST CONDITION SUMMARY

DEPLOYMENT LOADS

An empirical inflation loads prediction model has been developed based on a compilation of ARS and GPADS drop test data. The model has proved quite accurate in predicting inflation loads for the 3,600 ft^2 parafoils and was therefore used as the point of departure for predicting 7,350 ft^2 canopy inflation loads. Scaling factors which were believed to be appropriate were applied. The resulting "scaled-up" model was used to predict the loads upon which the large canopy's stress analysis was based. Drop Test No. 2-5 conducted early in January 1995 provided an opportunity to measure inflation loads and to compare them to those predicted for the design. Figure 4 compares predicted load values to actual loads experienced during DT 2-5. The actual load data was obtained from load cells incorporated in the suspension slings. The measured loads agree quite well with the prediction.

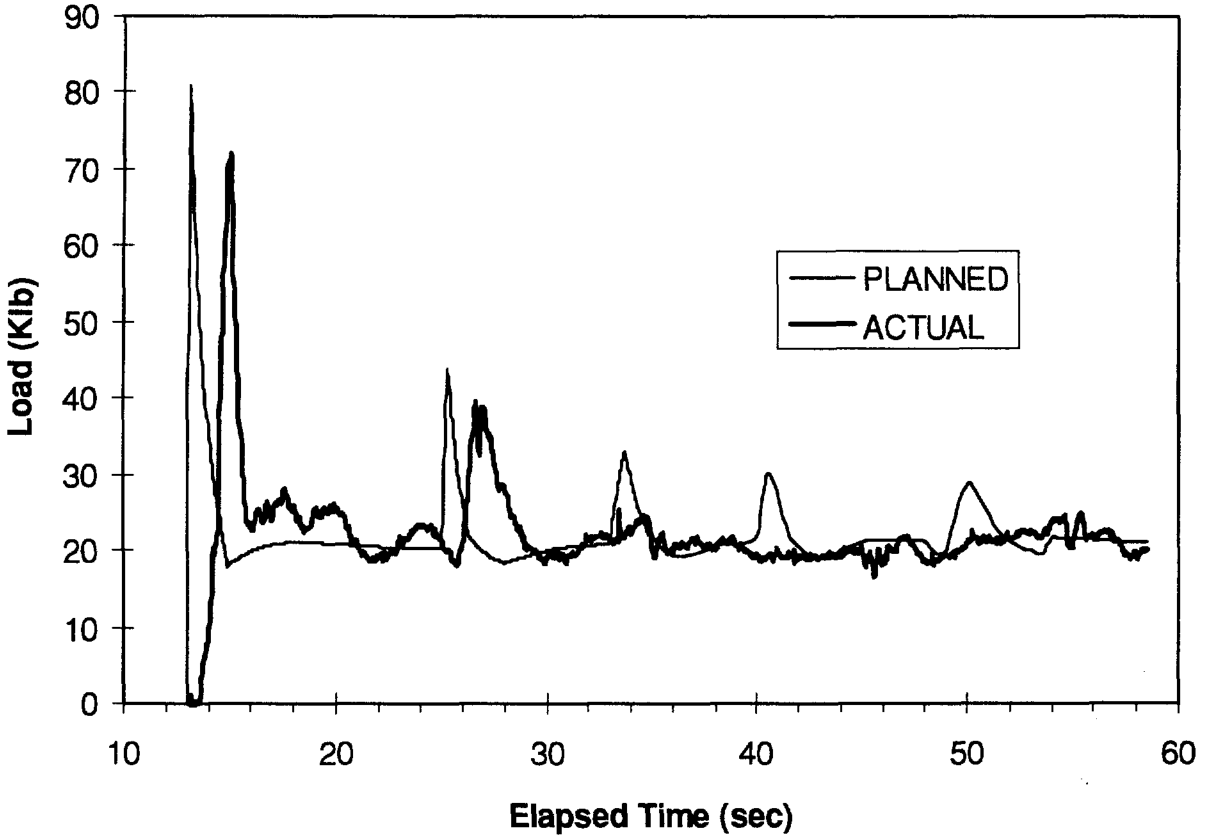


Figure 4, PREDICTED VS. ACTUAL LOADS

CONCLUSION

Initial drop tests of the large GPADS parafoil have been very encouraging. It's performance has been well within predicted ranges. The Natick GPADS payload exit criterion of 22,000 lb has been satisfied early in the program (DT 3-1). Subsequent tests will further increase payload weight, integrate guidance and control and measure performance. Gliding canopies of this size can clearly be built and flown in real world conditions thereby providing precision, offset aerial delivery for payloads in the 20,000 - 40,000 lb range. There is nothing in the behavior of the 7,350 ft^2 wing which indicates that a size limit is being approached. Larger wings can be built and reliably deployed.

ACKNOWLEDGMENTS

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